**This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record**

# BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- [x] BLACK BORDERS
- [ ] IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- [ ] FADED TEXT OR DRAWING
- [ ] BLURRED OR ILLEGIBLE TEXT OR DRAWING
- [ ] SKEWED/SLANTED IMAGES
- [ ] COLOR OR BLACK AND WHITE PHOTOGRAPHS
- [ ] GRAY SCALE DOCUMENTS
- [ ] LINES OR MARKS ON ORIGINAL DOCUMENT
- [ ] REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- [ ] OTHER: ______________________

**IMAGES ARE BEST AVAILABLE COPY.**
**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : H02J 7/00, G01N 27/416

A1

(11) International Publication Number: WO 00/67359

(43) International Publication Date: 9 November 2000 (09.11.00)

(21) International Application Number: PCT/US00/12214

(22) International Filing Date: 4 May 2000 (04.05.00)

(30) Priority Data:

| | | |
|---|---|---|
| 60/132,622 | 5 May 1999 (05.05.99) | US |
| 60/165,208 | 12 November 1999 (12.11.99) | US |
| 60/175,762 | 12 January 2000 (12.01.00) | US |

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant: MIDTRONICS, INC. [US/US]; 7000 Monroe Street, Willowbrook, IL 60521 (US).

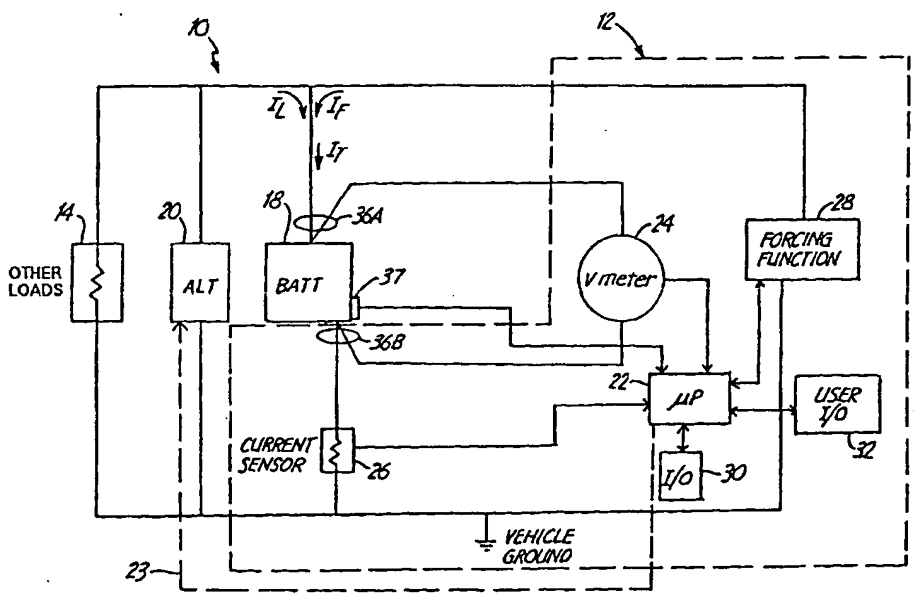
(72) Inventor: BERTNESS, Kevin, I.; 1317 McClurg Drive, Batavia, IL 60510 (US).

(74) Agents: CHAMPLIN, Judson, K. et al.; Westman, Champlin & Kelly, P.A., International Centre, Suite 1600, 900 Second Avenue South, Minneapolis, MN 55402-3319 (US).

**Published**

*With international search report.*

(54) Title: ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE




## (57) Abstract

A battery monitor (12) is provided for use with a battery (18) of an automotive vehicle (10). The battery monitor (12) can provide real time battery condition measurements and can selectively control the charging of the battery (18) through an alternator (20) of the vehicle (10) based upon the measured battery condition.

*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AL | Albania | ES | Spain | LS | Lesotho | SI | Slovenia |
| AM | Armenia | FI | Finland | LT | Lithuania | SK | Slovakia |
| AT | Austria | FR | France | LU | Luxembourg | SN | Senegal |
| AU | Australia | GA | Gabon | LV | Latvia | SZ | Swaziland |
| AZ | Azerbaijan | GB | United Kingdom | MC | Monaco | TD | Chad |
| BA | Bosnia and Herzegovina | GE | Georgia | MD | Republic of Moldova | TG | Togo |
| BB | Barbados | GH | Ghana | MG | Madagascar | TJ | Tajikistan |
| BE | Belgium | GN | Guinea | MK | The former Yugoslav Republic of Macedonia | TM | Turkmenistan |
| BF | Burkina Faso | GR | Greece | | | TR | Turkey |
| BG | Bulgaria | HU | Hungary | ML | Mali | TT | Trinidad and Tobago |
| BJ | Benin | IE | Ireland | MN | Mongolia | UA | Ukraine |
| BR | Brazil | IL | Israel | MR | Mauritania | UG | Uganda |
| BY | Belarus | IS | Iceland | MW | Malawi | US | United States of America |
| CA | Canada | IT | Italy | MX | Mexico | UZ | Uzbekistan |
| CF | Central African Republic | JP | Japan | NE | Niger | VN | Viet Nam |
| CG | Congo | KE | Kenya | NL | Netherlands | YU | Yugoslavia |
| CH | Switzerland | KG | Kyrgyzstan | NO | Norway | ZW | Zimbabwe |
| CI | Côte d'Ivoire | KP | Democratic People's Republic of Korea | NZ | New Zealand | | |
| CM | Cameroon | | | PL | Poland | | |
| CN | China | KR | Republic of Korea | PT | Portugal | | |
| CU | Cuba | KZ | Kazakstan | RO | Romania | | |
| CZ | Czech Republic | LC | Saint Lucia | RU | Russian Federation | | |
| DE | Germany | LI | Liechtenstein | SD | Sudan | | |
| DK | Denmark | LK | Sri Lanka | SE | Sweden | | |
| EE | Estonia | LR | Liberia | SG | Singapore | | |

# ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE

## BACKGROUND OF THE INVENTION

The present invention relates to automotive vehicles. More specifically, the present invention relates to an energy management and monitor system for a battery of an automotive vehicle.

Automotive vehicles powered by combustion engines typically include a battery. The battery is used to power the electrical system when the engine is not running. Additionally, the engine is used to charge the battery. The engine is also used to power electrical components of the vehicle when the engine is running.

Vehicles contain charging systems, simply referred to as an "alternator," which are powered by the engine and used to charge the battery. Typical prior art charging systems have been a simple voltage regulator connected to the output of an alternator. The voltage regulator is used to set a voltage generated by the alternator which is applied to the battery. However, this simple technique does not take into account the actual condition of the battery as the voltage across the battery is not an accurate representation of the battery's condition. Additionally, such systems do not provide any information about the use of the battery, or the battery's current state of charge or state of health.

## SUMMARY OF THE INVENTION

Various aspects of the present invention provide a method and/or an apparatus for monitoring or controlling charging of a battery in a vehicle. In one aspect, a method is provided for charging a battery in

a vehicle having an internal combustion engine configured to drive an alternator electrically coupled to the battery and adapted to charge the battery with a charge signal applied to the battery. The method includes coupling to the battery through a four point Kelvin connection, measuring a dynamic parameter of the battery using the Kelvin connection, where the dynamic parameter measurement a function of a time varying signal. A condition of the battery as a function of the measured dynamic parameter. The charge signal from the alternator is controlled in response to the determined condition of the battery.

In another aspect, an apparatus for monitoring the condition of a storage battery while the storage battery is coupled in parallel to an electrical system of an operating vehicle is provided. the apparatus includes a first electrical connection directly coupled to a positive terminal of the battery, a second electrical connection directly coupled to a negative terminal of the battery, and the first and second electrical connections are coupled to a voltage sensor to measure a time varying voltage across the battery. A third electrical connection is directly coupled to the positive terminal of the battery and a fourth electrical connection directly is coupled to a negative terminal of the battery, the third and fourth electrical connections are coupled to a forcing function having a time varying component. In one aspect, a current sensor is provided which is electrically in series with the battery. A microprocessor is configured to determine the condition of the battery as a function of a dynamic parameter of the battery based upon the measured voltage and the forcing function.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified block diagram showing a battery monitor in a vehicle in accordance with one embodiment of the present invention.

Figure 2 is a more detailed schematic diagram showing the battery monitor of Figure 1.

Figure 3 is a simplified block diagram showing steps in performing diagnostics in accordance with one aspect of the present invention.

Figure 4 is a simplified block diagram showing steps in collecting data for use with the present invention.

Figure 5 is a simplified block diagram which illustrates performing diagnostics on a starter motor of the vehicle of Figure 1.

Figure 6 is a simplified block diagram showing steps related to adjusting the charging profile for charging the battery of the vehicle of Figure 1.

Figure 7 is a graph which illustrates one sample curve of regulator voltage output versus state of charge for the battery of Figure 1.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

The present invention offers an apparatus and method for monitoring the condition of the battery and controlling charging of the battery. Such a method and apparatus can be part of a general energy management system for a vehicle.

Figure 1 is a simplified block diagram showing an automotive vehicle 10 which includes a battery monitor 12 in accordance with one embodiment of the present invention. Vehicle 10 includes vehicle loads 14 which are shown schematically as an electrical resistance. A battery 18 is coupled to the vehicle load 14 and to an alternator 20. Alternator 20 couples to an

engine of the vehicle 10 and is used to charge battery 18 and provide power to loads 14 during operation.

In general, automotive vehicles include electrical systems which can be powered when the engine of the vehicle is operating by a generator, or alternator. However, when the engine is not running, a battery in the vehicle is typically used to power the system. Thus, the standard generator system in a vehicle serves two purposes. The generator is used to supply power to the vehicle loads, such as lights, computers, radios, defrosters and other electrical accessories. Further, the generator is used to recharge the battery such that the battery can be used to start the vehicle and such that the battery may power the electrical accessories when the engine is not running.

A standard generator system typically consists of a three phase AC alternator coupled to the engine by a belt or a shaft, rectification diodes and a voltage regulator. These components may exist separately or be part of an integral unit and are typically, somewhat inaccurately, referred to as an "alternator". The voltage regulator is configured such that a constant voltage is supplied by the charging system, regardless of the current being drawn by the electrical system. The actual load applied to the generator system varies depending upon the number of accessories that are activated and the current required to recharge the battery. Typical values for the voltage regulator output are between 13.5 and 15.5 volts, depending upon the vehicle manufacturer and particular battery chemistry. Further, the voltage on a specific vehicle can also be compensated for ambient temperature.

This prior art approach has a number of draw backs. The output voltage of the generator must be

selected to be high enough to rapidly charge the battery under any condition and regardless of the state of charge of the battery. Electrical loads on the vehicle are designed to operate at 12.6 volts, the voltage provided by the battery when the engine is switched off. However, these electrical loads must also operate at the higher voltage supplied when the generator system is on. This higher voltage which is impressed upon the electrical system causes higher $I^2R$ (resistive) losses in the loads due to the increased voltage level. This wastes energy and causes the components to heat. This results in reduced life of the electrical circuitry, higher operating temperatures and wasted energy which must ultimately come from the primary fuel source used to operate the engine.

The high voltage across the battery is necessary when the battery's state of charge is low in order to rapidly recharge the battery. However, when the battery's state of charge is within an acceptable range (which occurs most of the time at normal driving speeds), the high voltage across the battery results in high $I^2R$ (resistive heating) losses within the battery resulting in waste of energy, heating of the battery causing premature battery failure, gassing of the battery also resulting in premature failure and heating of electrical components causing premature component failure.

One aspect of the present invention includes the recognition of the aforementioned problems associated with prior art battery charging techniques. In one aspect of the present invention, a battery charging system controller is provided which monitors the condition of the battery under charge and controls the charging system in response to the condition of the

battery. With such general aspects of the invention, the particular implementation of the battery monitor and charge control can be selected as appropriate.

In the embodiment illustrated in Figure 1, battery monitor 12 includes a microprocessor 22 coupled to a voltage sensor 24, a current sensor 26 and a forcing function 28. Microprocessor 22 may also include one or more inputs and outputs illustrated as I/O 30 adapted to couple to an external databus or to an internal databus associated with the vehicle 10. Further, a user input/output (I/O) 32 is provided for providing interaction with a vehicle operator. In one embodiment, microprocessor 22 is coupled to alternator 20 to provide a control output 23 to alternator 20 in response to inputs, alone or in various functional combinations, from current sensor 26, voltage sensor 24 and forcing function 28. In one embodiment, the control output 23 is configured to control alternator 20 such that a nominal voltage output from alternator 20 is 12.6 volts, typical of the nominal open-circuit voltage of the battery 18. Further, microprocessor 22 can raise the output voltage from alternator 20 in accordance with an inverse relationship to the state of charge of battery 18. This can be configured such that alternator 20 only charges battery 18 when necessary, and only charges battery 18 as much as is necessary. This charging technique can increase battery life, lower component temperature of loads 14, increase the lifespan of loads 14 and save fuel. This configuration provides a feedback mechanism in which the state of charge of battery 18 is used to control the charging of battery 18. The battery monitor 12 is easily installed in a vehicle electrical system. A single shunt current sensor 26 must be inserted in one of the primary battery

cables and a control line provided to allow control of alternator 20. The control can be by simply adjusting the voltage supplied to a voltage regulator of alternator 20 to thereby control charging of battery 18. The battery monitor 12 can be a separate, self-sufficient and self-contained monitor which operates without requiring interaction with other components of the vehicle, except in some embodiment, alternator 20.

Figure 1 also illustrates a Kelvin connection formed by connections 36A and 36B to battery 18. With such a Kelvin connection, two couplings are provided to the positive and negative terminals of battery 18. This allows one of the electrical connections on each side of the battery to carry large amounts of current while the other pair of connections can be used to obtain accurate voltage readings. Because substantially no current is flowing through the voltage sensor 24, there will be little voltage drop through the electrical connection between sensor 24 and battery 18 thereby providing more accurate voltage measurements. In various embodiments, the forcing function 28 can be located physically proximate battery 18 or be connected directly to battery 18. In other embodiments, the forcing function 28 is located anywhere within the electrical system of vehicle 10. In one aspect, the present invention includes an in-vehicle battery monitor 12 which couples to battery 18 through a Kelvin connection and further may optionally include a current sensor 26 and may be capable of monitoring battery condition while the engine of vehicle 12 is operated, loads 14 are turned on and/or alternator 20 is providing a charge signal output to charge battery 18. In one particular embodiment, the combination of the Kelvin connection formed by connections 36A and 36B along with a separate current

sensor 26 connected in series with the electrical system of the vehicle 10 is provided and allows monitoring of the condition of battery 18 during operation of vehicle 10. The use of an current sensor 26 is used to provide a monitor of the total current $I_T$ flowing through battery 18.

In operation, microprocessor 22 is capable of measuring a dynamic parameter of battery 18. As used herein, a dynamic parameter includes any parameter of battery 18 which is measured as a function of a signal having an AC or transient component. Examples of dynamic parameters include dynamic resistance, conductance, admittance, impedance or their combinations. In various aspects of the invention, this measurement can be correlated, either alone or in combination with other measurements or inputs received by microprocessor 22, to the condition or status of battery 18. This correlation can be through testing of various batteries and may be through the use of a lookup table or a functional relationship such as a characterization curve. The relationship can also be adjusted based upon battery construction, type, size or other parameters of battery 18. Examples of various testing techniques are described in the following references U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING; U.S. Patent No. 4,881,038, issued November 14, 1989, to Champlin,

entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING TO DETERMINE DYNAMIC CONDUCTANCE; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH STATE-OF-CHARGE COMPENSATION; U.S. Patent No. 5,140,269, issued August 18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR ASSESSING BATTERY/CELL CAPACITY; U.S. Patent No. 5,343,380, issued August 30, 1994, entitled METHOD AND APPARATUS FOR SUPPRESSING TIME VARYING SIGNALS IN BATTERIES UNDERGOING CHARGING OR DISCHARGING; U.S. Patent No. 5,572,136, issued November 5, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,574,355, issued November 12, 1996, entitled METHOD AND APPARATUS FOR DETECTION AND CONTROL OF THERMAL RUNAWAY IN A BATTERY UNDER CHARGE; U.S. Patent No. 5,585,728, issued December 17, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,592,093, issued January 7, 1997, entitled ELECTRONIC BATTERY TESTING DEVICE LOOSE TERMINAL CONNECTION DETECTION VIA A COMPARISON CIRCUIT; U.S. Patent No. 5,598,098, issued January 28, 1997, entitled ELECTRONIC BATTERY TESTER WITH VERY HIGH NOISE IMMUNITY; U.S. Patent No. 5,757,192, issued May 26, 1998, entitled METHOD AND APPARATUS FOR DETECTING A BAD CELL IN A STORAGE BATTERY; U.S. Patent No. 5,821,756, issued October 13, 1998, entitled ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,831,435, issued November 3, 1998, entitled BATTERY TESTER FOR JIS STANDARD; U.S. Patent No. 5,914,605, issued June 22, 1999, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 5,945,829, issued August 31, 1999, entitled MIDPOINT BATTERY MONITORING; U.S. Patent

No. 6,002,238, issued December 14, 1999, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES; U.S. Patent No. 6,037,777, issued March 14, 2000, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; and U.S. Patent No. 6,051,976, issued April 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST.

In the specific embodiment illustrated in Figure 1, the forcing function is a function which applies a signal having an AC or transient component to battery 18. The forcing function can be through the application of a load which provides a desired forcing function in which current is drawn from battery 18, or can be through active circuitry in which a current is injected into battery 18. This results in a current labeled $I_F$ in Figure 1. The total current, $I_T$ through battery 18 is due to both the forcing function current $I_F$ and the current flowing through loads 14, $I_L$. Current sensor 26 is positioned to sense the total current $I_L$. One example battery dynamic parameter, the dynamic conductance (or reciprocally the battery resistance) can be calculated as:

$$\Delta G - V - \Delta I_T/\Delta V \qquad \text{EQ. 1}$$

where $\Delta V$ is the change in voltage measured across the battery 18 by voltage sensor 24 and $\Delta I_T$ is the change in total current measured flowing through battery 18 using current sensor 26. Note that Equation 1 uses current and voltage differences. In one embodiment, the change in voltage and change in current are measured over a period of 12.5 seconds and at a rate of 50 msec to thereby provide a total of 20 readings for $\Delta V$ and $\Delta I_T$

every second. The forcing function 28 is provided in order to ensure that the current through battery 18 changes with time. However, in one embodiment, changes in $I_L$ due to loads 14 or the output from alternator 20 can be used alone such that $\Delta I_T = \Delta I_L$ and the forcing function 28 is not required.

In one embodiment, the voltage and current sensors provide synchronized operation, within one microsecond, and are substantially immune to measurement errors due to network propagation delays or signal line inductance. Furthermore, microprocessor 22 can detect a failure of the voltage regulator and alternator 20 if the voltage output exceeds or drops below predetermined threshold levels. This information can be provided to an operator through user interface 32, for example, a "service regulator soon" indication.

A temperature sensor 37 is provided which can be coupled directly to one of the terminals of the battery 18 for measuring battery temperature. The temperature sensor 37 can be used in determining the condition of the battery, as battery condition is a function of temperature and can be used in estimating the amount of power which will be required to start the engine of the vehicle. Any type of temperature sensor can be used, for example, a thermistor, thermocouple, RTD, semiconductor or other temperature sensor.

In one embodiment, current sensor 26 comprises a resistance shunt of 250 $\mu$ohms and current through the shunt is determined by measuring the voltage drop across the shunt. However, other types of current measurement techniques can also be used such as Hall Effect sensors or through an inductance probe. The change of voltage across the battery and the resultant change in current through the battery is sampled using, for example, one

or more analog to digital converters. This information can be correlated to determine the total capacity, such as the total Cold Cranking Amp (CCA) capacity of the battery.

Note that during the measurement cycle, vehicle loads 14 may be applied unexpectedly causing noise to be present in the measurements. One technique which might be considered to reduce the noise is to discard those samples which are outside of a predetermined or adjustable window or are outside of the dynamic range of the analog to digital converter. However, quite unexpectedly it has been found that the accuracy of measurements can be increased by increasing the dynamic range of the analog to digital converters, at the expense of the accuracy of the samples obtained from the converter. By averaging all of the samples, even those which are statistically large or small relative to other samples, the present invention is capable of providing accurate voltage and current measurements even in a noisy environment. By averaging samples, and providing sufficient dynamic range for the analog to digital converter, no samples will be discarded and errors in the measurements will tend to cancel against other errors.

In general, the present invention uses the direct relationship between the dynamic conductance of the battery and the condition of the battery. For example, if a battery drops more than 15% below its rated capacity, microprocessor 22 can provide an output which indicates that the battery 18 should be replaced. Further, the conductance can be used to determine the charge level of the battery. Such a measurement can be augmented to improve accuracy by monitoring the total current flowing into battery 18, or out of battery 18,

using current sensor 26. The voltage across the battery 18 can also be used to determine the charge used in the determination of charge level. In general, the state of charge can be determined as a function of various combinations either alone or together of battery state of health, temperature, charge balance (charge going into and out of the battery), charging efficiency and initial conditions such as the battery construction, manufacture, plate configuration or other conditions of the battery. The functional relationship can be determined by characterizing multiple batteries or through the use of artificial intelligence techniques such as neural networks.

Figure 2 is a more detailed schematic diagram of battery monitor 12. Figure 2 shows microprocessor 22 which includes a memory 40. Figure 2 illustrates I/O 32 with which can be, for specific examples, a communication link in accordance with various standards such as J1850, J1708, J1939, etc. Memory 40 is shown as an internal memory. However, external memory or an optional external memory 42 can also be provided. In general, memory is provided for storing programming functions, ratings, variables, etc. Microprocessor 22 can be a microcontroller or any type of digital circuitry and is not limited specifically to a microprocessor. Figure 2 illustrates forcing function 28 in greater detail and includes a resistance $R_1$ 44 and a switch $S_1$ 46 controlled by microprocessor 22. Switch 46 can be, for example, a field effect transistor. Voltage sensor 24 is shown as including a differential amplifier 47 coupled to battery 18 through a DC blocking capacitor $C_1$ 48. Shunt 26 is illustrated as a resistance $R_2$ 50 and a differential amplifier 52. Switches $S_2$ 54 and $S_3$ 56 are positioned to selectively

couple amplifiers 52 and 47, respectively, to microprocessor 22 and are actuated by a sample control line to provide data samples to microprocessor 22. An analog to digital converter can be an integral part of microprocessor 22 or it can be a separate component to digitize the outputs from amplifiers 47 and 52. Capacitors $C_2$ and $C_3$ provide sample and hold circuits.

Forcing function 28 can be formed by resistance as illustrated in Figure 2, or by a current sink or through an existing load of the vehicle. Switch $S_1$ 46 can be an FET, or biopolar transistor or can be a mechanical or existing switch in the automotive vehicle. Although shunt 26 is illustrated with a shunt resistance, other types of current sensors such as Hall effect sensors or cable resistance based sensors can be used. Other types of DC blocking techniques can be used to replace capacitancy $C_1$ 48 such as a DC coupled amplifier.

Figure 3 is a simplified block diagram 100 showing diagnostic steps performed by microprocessor 28 in accordance with the invention. At blocks 102 and 104, the dynamic parameter(s) for the battery 18 are obtained and at block 104 data is collected. The type of data collected at block 104 can be any type of data used in determining the condition of the battery. For example, the data can be values used for $\Delta V$ and $\Delta I_T$, information related to the type of battery, etc. This information can be stored in memory 40 for subsequent retrieval by microprocessor 22. The data can be collected over any time period and during any type of engine or battery operation. At block 106, microprocessor 22 performs diagnostics based upon the data stored in memory 40. If a battery fault or impending fault is detected, an output can be provided

at block 108 such as providing a "service battery soon" indication on the dash of the vehicle 10.

Various aspects of the invention include the particular diagnostics performed by diagnostic block 106. The diagnostics can be simple diagnostics such as a simple if-then rule in which the collected data is compared to various thresholds to provide the diagnostic output. Absolute values of the data can be used for this comparison or various statistical operations can be performed on the data for use in the comparison. For example, averages or standard deviation of the data can be compared to a threshold. The threshold levels can be determined through testing of the vehicle and entered into memory 40 during manufacture. Preferably, when battery 18 is replaced, the thresholds are updated accordingly.

In more advanced embodiments of the diagnostic block 106, microprocessor 22 can perform diagnostics using fuzzy logic, neural networks or artificial intelligence techniques. Neural networks can advantageously be used as they do not require that the battery, alternator and vehicle loads be modeled. Instead, neural networks are capable of learning what "normal" data collected at step 104 should be, and can provide an indication when a pattern of the data is drifting outside of normal operation. Further, the neural network can be "trained" to recognize potential sources of the failure and provide an expected time until the system completely fails. These diagnostic techniques can be selected and implemented such that the operator is warned of an impending failure, prior to the complete failure of the battery 18 or alternator 20.

Figure 4 is a block diagram 130 showing example steps in accordance with data collection and

calculation of a dynamic parameter in accordance with the present invention. Of course, as should be pointed out with respect to all of the flow charts set forth herein, those skilled in the art will recognize that the particular functions of the blocks and the order in which the blocks are executed can be easily rearranged and the invention is not limited to the specific embodiments set forth herein.

In block diagram 130, at block 132 microprocessor 22 obtains an initial voltage $V_1$ across battery 18 using voltage sensor 24 and an initial current $I_{T1}$ through battery 18 using current sensor 26. Next, the forcing function 28 is applied to battery 18 at step 133. At block 134, microprocessor 22 obtains values $V_2$ and $I_{T2}$ with the forcing function applied, and at step 136 the forcing function is removed. Values for $\Delta V$ and $\Delta I_T$ are calculated at step 138. In one example embodiment, the forcing function is applied for a duration of 100 $\mu$Sec 20 times every second. N values are obtained at block 140. In one example, N is equal to 256. At block 142, the average of $\Delta V$ and $I_{T2}$ for the N samples is calculated and a dynamic parameter for the batter 18 is determined at block 144. This dynamic parameter can be correlated to a condition of the battery at block 146 and displayed on user I/O 32, output through I/O 30 or used to control alternator 20 through alternator control 23.

In one aspect of the invention, the battery monitor performs a state of charge measurement, in real time and regardless of battery polarization, and automatically corrects for the state of health of the battery and the battery temperature. In general, state of health can be determined as a function of the battery conductance and the open circuit voltage across battery

18. For example, the state of health can be determined as:

EQ. 2

where $k_1$ and $k_2$ are constants which are related to the type of battery, G is the measured conductance of the battery, rating is a rating for the battery and $f(V_{OC})$ is a relationship between the state of charge and the open circuit voltage of the battery as set forth in the aforementioned Champlin and Midtronics, Inc. patents. The state of health will range between 0 and 100%. Using the state of health determined by Equation 2, the state of charge (from 0 to 100%) can be determined in accordance with Equation 3:

$$SOCt_2 = 100 * \frac{\left[\int_{t_1}^{t_2} i\,dt \int_{t_1}^{t_2} e(T)\,dt \int_{t_1}^{t_2} e(i)\,dt\right]}{(SOH)\ (AMP\text{-}HOURCAPACITY)} + SOC_{t_1} \qquad \text{EQ. 3}$$

where $t_1$ is the time at which the state of charge is known (i.e., from the period of overcharge, for example), $t_2$ is the present time, i is the current (amps) in or out of the battery at time t, T is the battery temperature, e(T) is the charge acceptance efficiency at temperature T, and e(i) is the charge acceptance efficiency at current i. Of course, Equations 2 and 3 are simply examples of state of health and state of charge measurements and other techniques can be used in accordance with the invention.

Using the battery state of charge and the battery state of health, battery monitor 12 can predict the starting capabilities of a starter motor of vehicle 10. For example, by comparing the amount of current measured by current sensor 26 which has been previously

been required to start the engine of vehicle 10 for a particular temperature, microprocessor 22 can determine if the current state of charge of the battery for the current state of health at the current temperature will be sufficient to provide enough current to start the engine. The performance and any degradation in the starter motor can also be taken into account by microprocessor 22. For example, if the amount of current required to start the engine has been increasing with time, microprocessor 22 can extrapolate and predict what amount of current will be required to start the engine in the future. Figure 5 is a simplified block diagram 200 which illustrates steps performed by a microprocessor 22 in diagnosing the starting capability of battery 18. At block 202, microprocessor 22 determines the starting capability of battery 18. For example, the starting capability can be an estimation or measurement of the amount of current which battery 18 can supply over a short duration. At block 204, microprocessor 22 estimates the starting requirements of the starting motor of the engine of vehicle 10. For example, the past requirements of the starter motor can be recalled from memory 40 and any trend can be used to predict what will be required for starting the engine. Other inputs can also be used in this determination such as the current temperature. At block 206, a starter diagnostic output is provided. For example, if it appears that the battery will have difficulty in operating the starter motor for a sufficient duration to start the motor of the vehicle, vehicle loads 14 can be selectively switched off by microprocessor 22 through I/O 30. Additionally, a warning can be provided to an operator through user I/O 32 of an impending problem,

prior to its actual occurrence, such that the battery 18 can be replaced.

In another aspect of the invention, microprocessor 22 can be adapt or alter the performance of the engine and/or loads 14 based upon a number of different parameters in order to provide optimal charging to battery 18. For example, microprocessor 22 can interface to a data bus of a microprocessor of the vehicle 10 through I/O 30 to control engine operation. Alternatively, microprocessor 22 can be the same microprocessor used to control vehicle operation. The microprocessor 22 can adjust the idle speed of the engine, shift points of the transmission and the load placed on the electrical system by some of the loads 14 to increase or decrease the rate of battery charging based upon the expected driving patterns of an operator. For example, if the microprocessor has observed that the vehicle is normally operated for a short duration, the microprocessor 22 can increase the idle speed of the engine and attempt to reduce loads placed on battery 18 to increase the charging rate of battery 18. Further, microprocessor 22 can alter the shift points of the transmission to cause the engine to operate at a high (or lower) speed than normal. The prediction of engine operation can also be based upon time of day and the day of the week such that repeated driving patterns can be accounted for, for example, commuting to work. Further, in vehicles where it is possible to recognize the operator of the vehicle, such as through the seat position memory in a power seat of the vehicle, microprocessor 22 can alter the charging pattern based upon the driving characteristics of a specific driver.

Figure 6 is a simplified block diagram flowchart 250 showing steps performed by microprocessor

22 in adjusting engine speed or loads to control the charge in battery 18. Block 252, microprocessor 22 determines the charge required by battery 18 to become fully charged, this determination can be based upon a measurement of the current charge level of battery and a determination of the maximum amount of charge that battery 18 can hold, for example, as a function of the state of health of battery 18. At block 254, microprocessor 22 predicts the expected driving pattern for the upcoming engine use. At block 256, microprocessor 22 adjusts the engine operation and/or vehicle loads 14 in order to optimize the charging of the battery 18 based upon the charge required as determined at step 252 and the driving pattern predicted at step 254. During engine operation, microprocessor 22 continues to monitor the battery state of charge at block 258 and adjusts the charging accordingly at block 260. Once battery 18 has been fully charged, the microprocessor 22 can reduce the charging rate as appropriate.

If the drive cycle is, or has tendency to be, insufficient to charge the battery 18, microprocessor 22 can provide an output to an operator through user I/O 32 to indicate that either the vehicle must be driven for an extended period of time or an alternative charging method be used to charge battery 18. An indication can also be provided as to a prediction regarding how many further such drive cycles can be supported by the battery 18 before it will have insufficient remaining charge to start the vehicle.

As discussed above, in one aspect of the present invention, the output from the alternator 20 is adjusted based upon the state of charge and/or the state of health determination(s). Figure 7 is a graph showing

the regulator voltage output from alternator 20 as a function of the state of charge of battery 18. As illustrated in Figure 7, microprocessor 22 reduces the voltage output from alternator 20 as the state of charge of battery 18 increases to 100% charge. The particular profile can be adjusted to a specific battery, alternator and/or engine configuration or to the driving characteristics of an operator. Such a system can significantly reduce or eliminate overcharging of battery 10 and the generation of excessive heat. Further, such a technique can be used to reduce or eliminate the undercharging of battery 10. Additionally, by adjusting the voltage based upon the state of charge, battery 18 and system component life will increase. For example, vehicle loads 14 will be exposed to over voltages for a reduced amount of time. This also allows the various systems components to be optimized for particular charging requirements or voltage levels. In general, the output of the alternator 20 can be reduced and the battery capacity required for a particular vehicle can be reduced because battery charge will be more efficiently maintained. This can reduce overall vehicle weight and improve vehicle mileage. Further still, IR (current-resistance) type losses in the electrical system and overcharging will be reduced thereby reducing the load on the vehicle engine and improving efficiency of the vehicle. In general, this technique will improve vehicle reliability by reducing heat due to excessive IR losses, increasing battery life, providing early detection of impending battery failure and insuring proper vehicle operation even with after market batteries which are used to replace the original battery.

If such a system is implemented when the vehicle is originally manufactured, monitor 12 allows battery management over the entire life of the vehicle. This can be both during assembly and delivery of the vehicle as well as during the lifespan of actual vehicle operation. Additionally, one aspect includes a storage battery 18 with rating information carried in a computer storage device such as a digital memory within a housing of the battery. This data can be communicated to monitor 12 through I/O 30. In one aspect, the electrical connections to the battery are also used as a data communication bus such that monitor 12 can communicate with the storage device in battery 18. The storage device can also be used to store the history, such as the charging and usage history, of battery 18.

Battery monitor 12 can monitor and diagnose operation of alternator 20. For example, a typical alternator provides a multiphase output. By monitoring the data points collected and stored in memory 40, microprocessor 22 can observe the loss of one or more phases in the alternator's output. Similarly, the failure of a rectifying diode in alternator 20 can be detected by microprocessor 22 by observing an asymmetrical ripple pattern. Microprocessor 22 can provide an output to an operator through user I/O 32 such as a "service alternator soon" output. This information can also be communicated to the vehicle microprocessor through I/O 30.

I/O 30 is shown in schematic form and can be any type of input or output and represents, in some embodiments, multiple input(s) and output(s). Various examples of inputs and outputs include a connection to a databus of the vehicle, a connection to a databus adapted to couple to a diagnostic device such as that

provided in service equipment, a connection to a remote vehicle monitoring system, such as one that is capable of coupling through a cellular phone connection of the vehicle. In such an embodiment, the vehicle is capable of recording and reporting information to a remote service such as an emergency assistance service or a service provided to monitor the operation of the vehicle and suggest that maintenance be provided. Various types of inputs and outputs can be provided through direct connections or through non-physical connections such as radio frequency or infrared communication techniques. The particular form of the data and standard used for the inputs and outputs can be selected as proprietary or industry standards. Microprocessor 22 can also be capable of providing advanced reporting and control functions through the use of standardized interfaces such as are available through HTML, XML, or various known or proposed alternatives. In such an embodiment, information collected by microprocessor 22 can be viewed through a "web page" interface provided by a browser. Such an embodiment is advantageous because it can provide a user input/output such as user I/O 32 in a standardized form such that it can be viewed or controlled through many types of standardized devices. In such an embodiment, information can be reported to, or the monitor 12 can be controlled, from a remote location. Additionally, if the vehicle 10 includes a browser type interface which may become commonly available in vehicles, the microprocessor 22 can be controlled and communicate through the vehicle's browser. In one aspect, vehicle monitor includes an IP (Internet Protocol) address such that it is capable of communicating in accordance with the Internet Protocol. When coupled to, for example, a cellular telephone

connection of the vehicle, the battery monitor 12 is capable of being monitored and controlled from a remote location coupled through the Internet. However, as mentioned above, such an interface also provides a simple technique for interfacing the monitor 12 with a local computer in the vehicle and displaying information from the monitor 12 for use or control by an operator.

Through the use of the data collected by microprocessor 22 and memory 40, microprocessor 22 is also capable of detecting the imminent failure of the starter motor of the vehicle. For example, by monitoring the voltage drop through the system during starting, microprocessor 22 can determine the average time to start the engine and the average and peak currents required during starting. Changes in these, or other, measurement values can indicate a degrading starter motor. Upon detection of an impending failure, a "service starter motor soon" indication can be provided to an operator through user interface 32.

Microprocessor 22 can provide an indication that the battery 18 has insufficient capacity or substandard performance and alert an operator accordingly. For example, upon power up, such as that which occurs when battery 18 is replaced, microprocessor 22 can measure the capacity of the battery 18 and provide an indication to the operator if the capacity is less than a threshold level determined by the vehicle manufacturer and stored in the memory of the vehicle computer system.

Microprocessor 22 can generate an audit code (or a warranty code) in response to the various tests and data collected. Such codes are described in U.S. Patent No. 6,051,976, issued April 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST which

is assigned to the present assignee. In such an embodiment, microprocessor 22 encodes data collected or obtained during its operation. For example, raw data related to a battery test can be obtained and/or the ultimate result of the battery test and subsequently encoded by microprocessor 22. The encoding can be a simple transposition cipher in which the locations and values of various bytes of information are rearranged. Such a code can be designed to prevent falsification of data which can occur where unscrupulous individuals are attempting to submit a falsified warranty claim for a failed component to a manufacturer. This coding technique allows the manufacturer to verify information when a warranty is submitted. Additionally, the information can be used to track operator error and assist in identification and isolation of component failure in order to redesign the components and reduce such failures.

In another aspect, microprocessor 22 is capable of automatically calibrating the measurements obtained from voltage sensor 24 and current sensor 26. Using this aspect of the invention, microprocessor 22 can perform automatic or periodic calibrations to maintain accuracy over the lifespan of the vehicle. Automatic calibration can be provided by selectively switching in calibrated elements having known temperature and time drift characteristics, and using the measured data to correct for instrumentation gains and offsets. For example, a known resistance or voltage source can be selectively coupled to amplifiers 47 or 52. Any offset values from these known values can be stored in memory 40 and used by microprocessor 22 to compensate for errors in measurements.

With the present invention, any polarization of the battery 18 such as that which can result from charging or starting operations; does not produce errors in the measurements performed by microprocessor 22. Specifically, any such errors are eliminated by use of a real-time state of charge algorithm that is independent of the real time battery terminal voltage.

When the engine of vehicle 10 is not operating, microprocessor 22 can enter a sleep mode to reduce current draw and the resultant discharge of battery 18. If desired, microprocessor 22 can periodically "wake up" to perform tests or monitor some aspect of the electrical system of vehicle 10.

A loose or corroded connection to battery 18 can be detected by microprocessor 22 by observing a sudden increase in the resistance across battery 18. An error can be provided to an operator through user interface 32 to alert the operator of the degraded connection.

Microprocessor 22 can also perform diagnostics on the electrical system of vehicle 12 when the engine is not operating. For example, microprocessor 22 can monitor the current being drawn by loads 14 when the engine is not running using current sensor 26. For example, microprocessor 22 can compare the rate of current draw, over a selectable sample period with a threshold stored in memory 40. If the measured rate exceeds the threshold, there may be a fault in the electrical system of the vehicle. Similarly, a small but constant current drain can also indicate a fault which could lead to the discharge of battery 18. Microprocessor 22 can provide an indication to the user through user interface 32 that excessive current draw has occurred while the engine is off. Such current draw

can lead to rapid discharge of battery 18 and prevent starting.

Current sensor 26 can also be used by microprocessor 22 to monitor the current flowing into and out of battery 18. The summation of this current, taken over a time period (i.e., integration) can provide an indication that the battery is not receiving sufficient charge, or can provide an indication of the total charge received by battery 18. This information can be displayed to an operator through user I/O 32. Additionally, the information can be provided on I/O 30. If the information indicates that the battery 18 is not receiving sufficient charge, steps can be taken as discussed above, to increase the charging rate of battery 18.

In one embodiment, microprocessor 22 stores information in memory 40 related to the model number, and/or serial number, capacity or other information related to battery 18. In such an embodiment, battery monitor 12 can be a physical part of battery 18 such that battery specific information can be programmed into memory during manufacture. The battery monitor 12 can provide an output to an operator through a display or other type of output device which is physically located on the battery 18. Additionally, the display or user I/O 32 can be located within the vehicle. Input/output 30 can be configured to couple to the databus of the vehicle. For example, the battery 18 can include a data plug adapted to plug into the databus of the vehicle such that monitor 12 can exchange information through the databus. Microprocessor 22 can then report this information to the databus of the vehicle using input/output 30. This allows the microprocessor of the

vehicle the ability to perform advanced diagnostics and monitoring as the specific battery type is known.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, the circuitry and circuit configuration is provided as simply one embodiment and those skilled in the art will recognize that other configurations can be provided. The particular connections to the battery can be through Kelvin connections which include a "split" Kelvin connection in which the forcing function connection(s) are/is spaced apart from the battery. In a further example of the present invention, alternator 20 can comprise an electronic battery charger such as those used to charge automotive vehicles when the vehicle is stationary or to charge stand by batteries such as those used in remote systems such as cellular sites. In such an embodiment, control line 23 is used to adjust the charger of battery 18 using the techniques set forth herein. In such an embodiment, element 10 shown in Figure 1 illustrates a standby power supply for equipment.

WHAT IS CLAIMED IS:

1. A method of charging a battery in a vehicle having an internal combustion engine configured to drive an alternator electrically coupled to the battery and adapted to charge the battery with a charge signal applied to the battery, the method comprising:

coupling to the battery through a four point Kelvin connection;

measuring a dynamic parameter of the battery using the Kelvin connection, the dynamic parameter measurement a function of a time varying signal;

determining a condition of the battery as a function of the measured dynamic parameter; and

controlling the charge signal in response to the determined condition of the battery.

2. The method of claim 1 wherein determining a condition of the battery includes determining a state of charge of the battery and wherein the charge signal is controlled according to the determined state of charge.

3. The method of claim 1 wherein controlling the charge signal comprises regulating a charging voltage applied to the battery according to the determined condition of the battery.

4. The method of claim 2 wherein controlling the charge signal comprises regulating a charging voltage applied to the battery according to the determined state of charge.

5. An apparatus for monitoring the condition of a storage battery while the storage battery is coupled in parallel to an electrical system of an operating vehicle, comprising:

a first electrical connection directly coupled to a positive terminal of the battery;

a second electrical connection directly coupled to a negative terminal of the battery, the first and second electrical connections coupled to a voltmeter to measure a time varying voltage across the battery;

a third electrical connection directly coupled to the positive terminal of the battery;

a fourth electrical connection directly coupled to a negative terminal of the battery, the third and fourth electrical connections coupled to a forcing function having a time varying component;

a current sensor electrically in series with the battery; and

a microprocessor configured to determine the condition of the battery as a function of a dynamic parameter of the battery based upon the measured voltage, the forcing function and the current sensed by the current sensor.

6. The apparatus of claim 5 further comprising an alternator electrically coupled to the battery and adapted to charge the battery with a charge signal applied to the battery in response to an alternator control signal, wherein the alternator control signal is produced by the microprocessor as a function of the dynamic parameter.

7. The apparatus of claim 6 wherein the charge signal comprises a charging voltage.

8. The apparatus of claim 5 wherein the microprocessor is configured to determine a state of charge of the battery as a function of a dynamic parameter of the battery based upon the measured voltage, the forcing function and the current sensed by the current sensor.

9. The apparatus of claim 8 further comprising an alternator electrically coupled to the battery and adapted to charge the battery with a charge signal applied to the battery in response to an alternator control signal, wherein the alternator control signal is produced by the microprocessor as a function of the determined state of charge.

10. The apparatus of claim 9 wherein the charge signal comprises a charging voltage.

11. The apparatus of claim 9 wherein the microprocessor is further configured to produce a vehicle-performance-parameter control signal based upon the determined state of charge, wherein the vehicle-performance-parameter control signal controls a vehicle performance parameter that affects the magnitude of the charge signal applied to the battery.

12. The apparatus of claim 8 wherein the microprocessor is further configured to determine a state of health of the battery as a function of a dynamic parameter of the battery based upon the measured voltage, the forcing function and the current sensed by the current sensor, wherein the apparatus further comprises a computer memory device configured to store data regarding the starting performance of the battery as a function of state of health and state of charge, and wherein the microprocessor is further configured to

determine a likelihood that the vehicle will start based upon the determined state of health, the determined state of charge and the stored starting performance data.

13. A method of determining the starting capability of a vehicle, comprising:

determining a state of charge of a vehicle battery;

determining a state of health of the vehicle battery;

determining a previous starting performance of the vehicle under similar conditions to the determined state of charge and state of health; and

determining a likelihood that the vehicle will start based upon the previous starting performance.

14. A method of controlling the charging rate of a vehicle storage battery during operation of the vehicle, comprising:

determining the state of charge of the battery;

charging the battery with a charge signal generated by an alternator; and

controlling a vehicle performance parameter based upon the determined state of charge, wherein the vehicle performance parameter is a parameter that affects the magnitude of the charge signal generated by the alternator.

15. A method of detecting that an initially installed vehicle battery has been replaced with a second vehicle battery, comprising:

measuring a value of a battery performance parameter;

calculating the difference between the measured value of the performance parameter and a predetermined value of the performance parameter; and

determining whether the initially installed vehicle battery has been replaced by a second battery based upon the difference between the measured value of the performance parameter and the predetermined value of the performance parameter.

16. A vehicle storage battery comprising:

a plurality of electrochemical cells, each having a plurality of positive plates and a plurality of negative plates;

an enclosure housing the electrochemical cells and having a positive terminal and a negative terminal disposed thereon;

a first connector electrically coupling adjacent cells to one another and electrically coupled to the positive terminal;

a second connector electrically coupling adjacent cells to one another and electrically coupled to the negative terminal; and

a computer data storage device contained in or coupled to the enclosure and adapted to store information regarding the battery, the storage device further configured to communicate with a device for testing the battery.

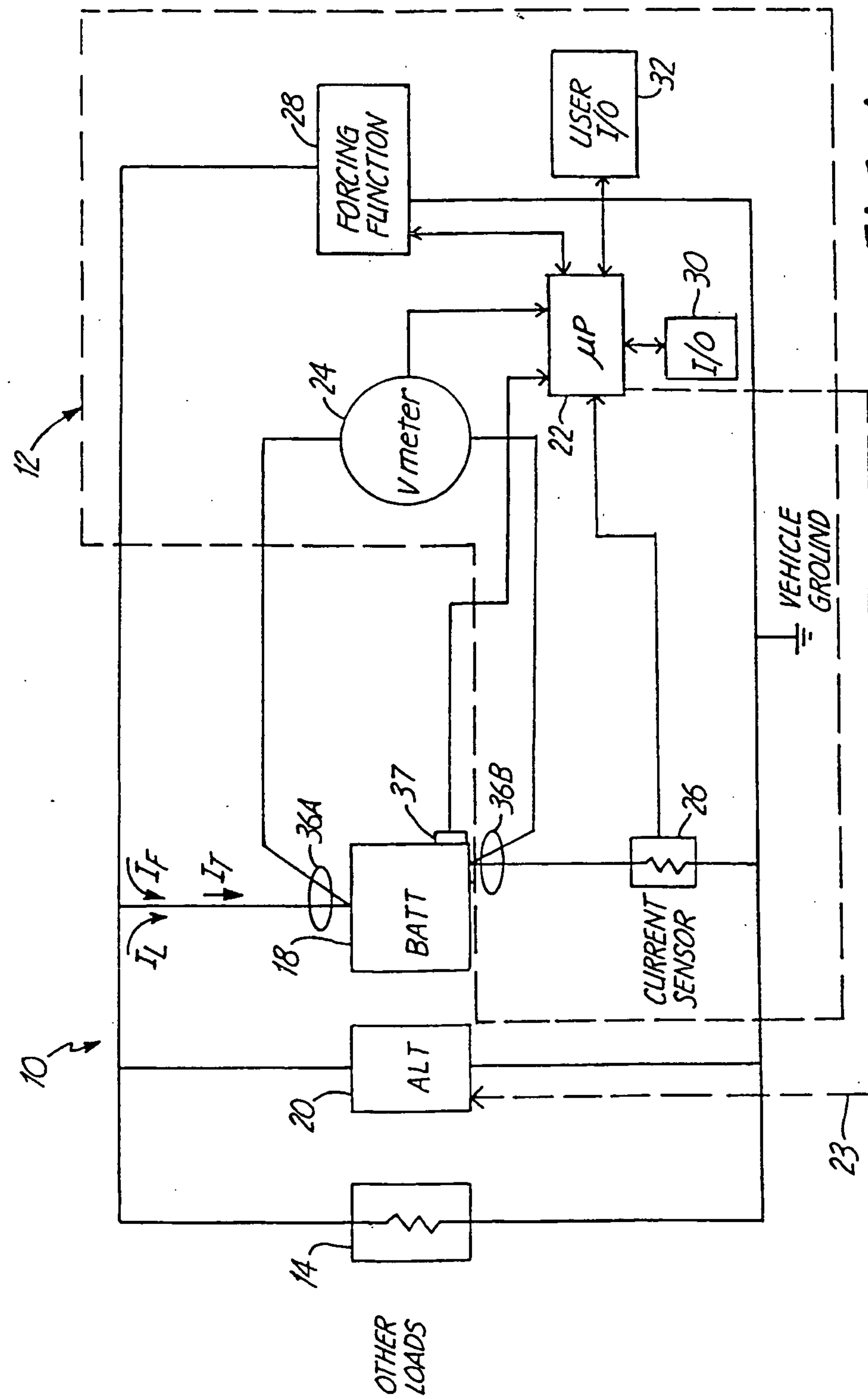
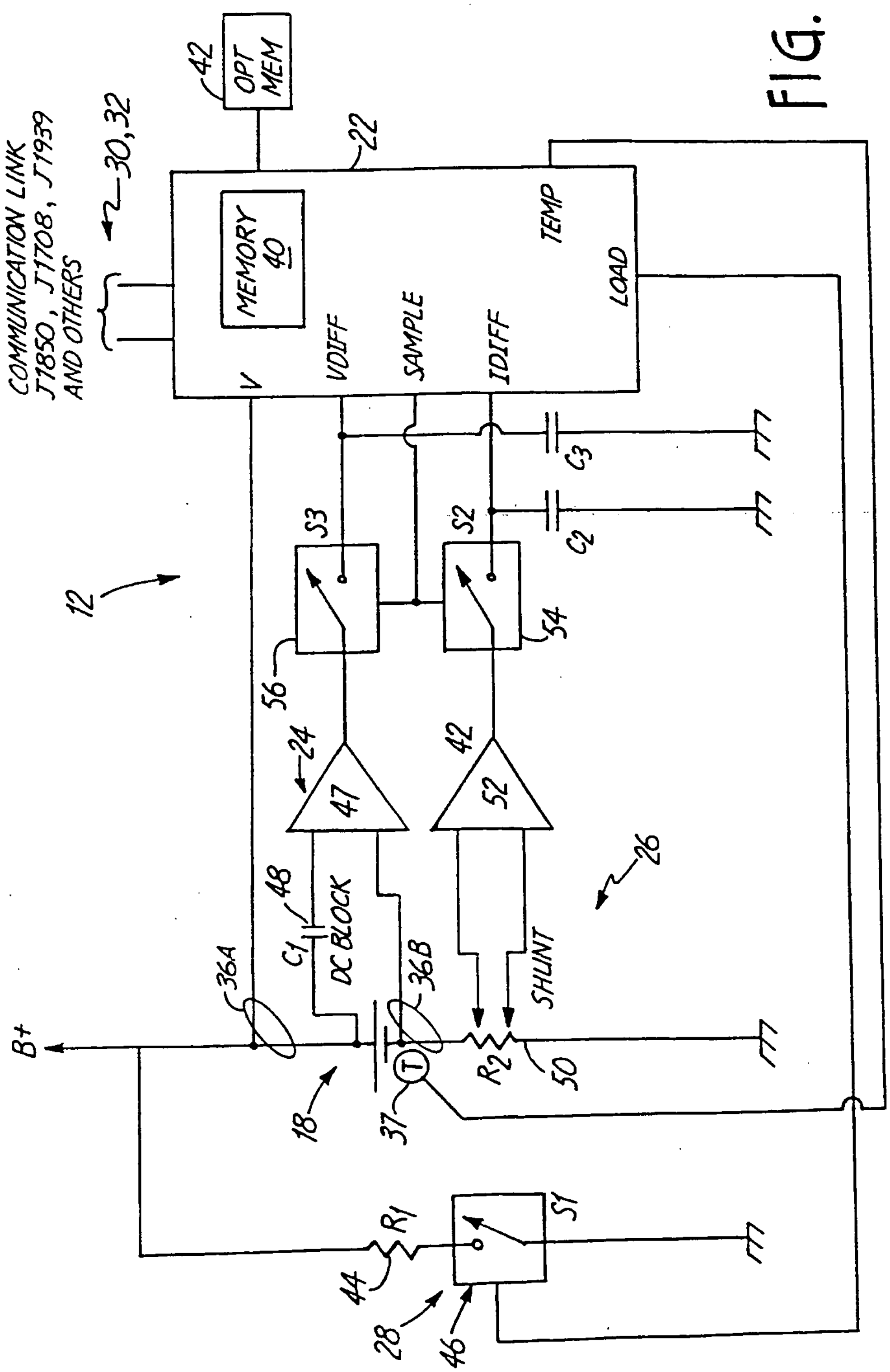

FORCING FUNCTION
28
USER I/O
32
μP
22
I/O
30
V meter
24
12
VEHICLE GROUND
10
$I_F$
$I_T$
$I_L$
36A
37
36B
BATT
18
26
CURRENT SENSOR
ALT
20
23
14
OTHER LOADS

FIG. 1



COMMUNICATION LINK J1850, J1708, J1939 AND OTHERS
30,32
42
OPT MEM
22
MEMORY 40
V
VDIFF
SAMPLE
IDIFF
TEMP
LOAD
C3
C2
S3
S2
12
56
54
24
47
42
52
26
48
C1
DC BLOCK
36A
36B
SHUNT
B+
18
T
37
R2
50
R1
44
S1
28
46


FIG. 2

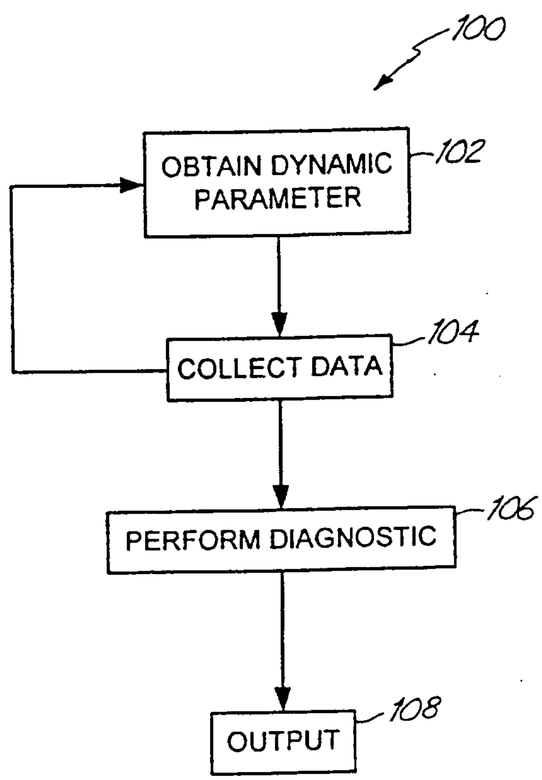

100
OBTAIN DYNAMIC PARAMETER
102
COLLECT DATA
104
PERFORM DIAGNOSTIC
106
OUTPUT
108

FIG. 3

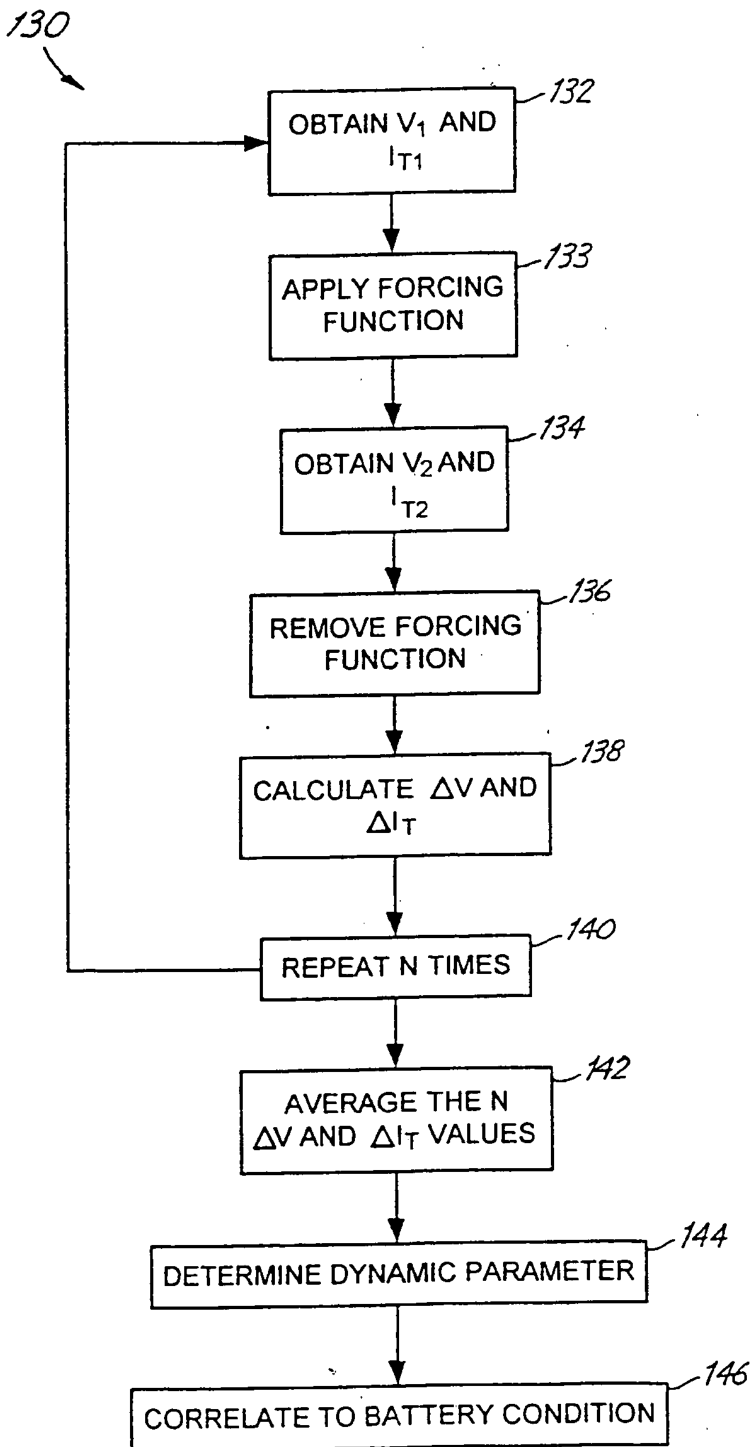

130
OBTAIN $V_1$ AND $I_{T1}$
132
APPLY FORCING FUNCTION
133
OBTAIN $V_2$ AND $I_{T2}$
134
REMOVE FORCING FUNCTION
136
CALCULATE $\Delta V$ AND $\Delta I_T$
138
REPEAT N TIMES
140
AVERAGE THE N $\Delta V$ AND $\Delta I_T$ VALUES
142
DETERMINE DYNAMIC PARAMETER
144
CORRELATE TO BATTERY CONDITION
146

FIG. 4

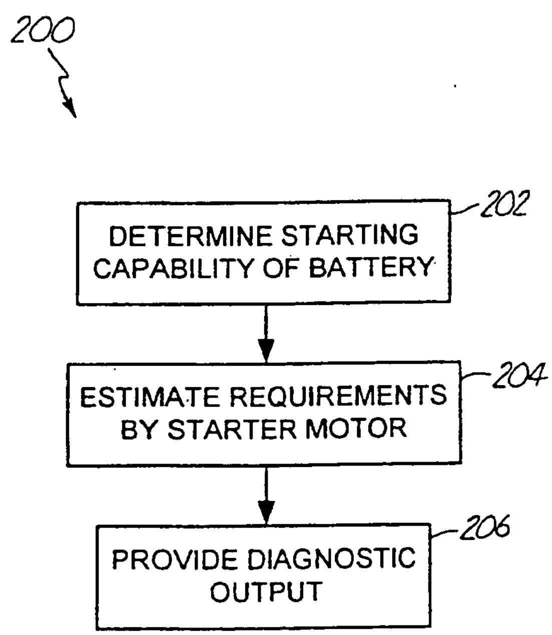

200
DETERMINE STARTING CAPABILITY OF BATTERY
202
ESTIMATE REQUIREMENTS BY STARTER MOTOR
204
PROVIDE DIAGNOSTIC OUTPUT
206

FIG. 5

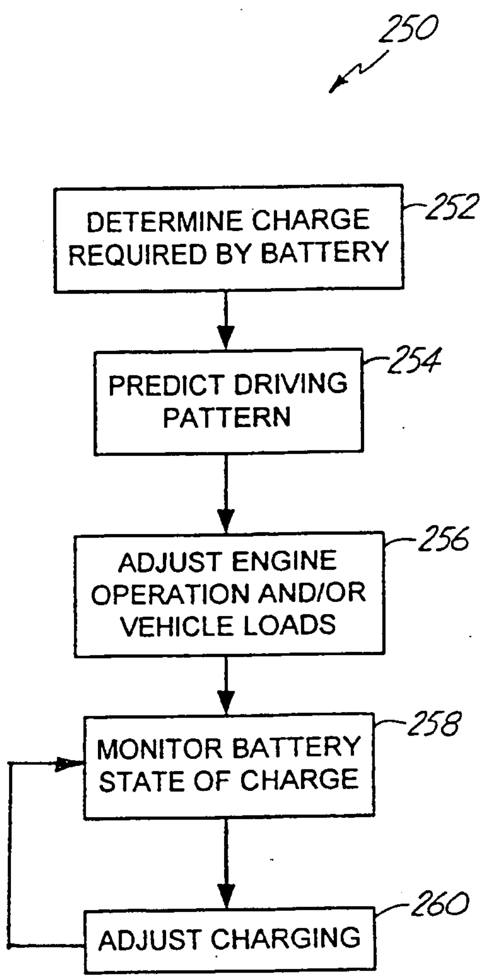
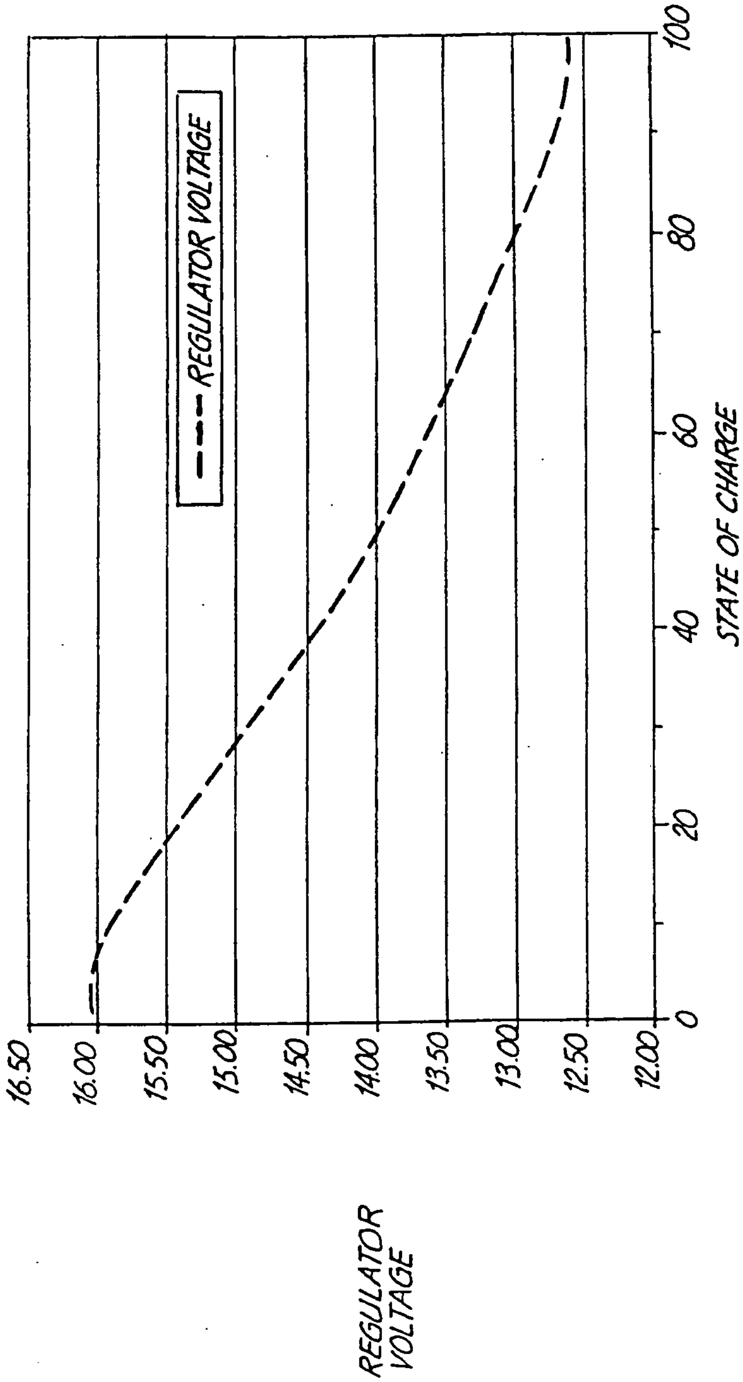

250
DETERMINE CHARGE REQUIRED BY BATTERY
252
PREDICT DRIVING PATTERN
254
ADJUST ENGINE OPERATION AND/OR VEHICLE LOADS
256
MONITOR BATTERY STATE OF CHARGE
258
ADJUST CHARGING
260

FIG. 6



REGULATOR VOLTAGE
16.50
16.00
15.50
15.00
14.50
14.00
13.50
13.00
12.50
12.00
0
20
40
60
80
100
STATE OF CHARGE
REGULATOR VOLTAGE


FIG.7

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/12214

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : H02J 7/00; G01N 27/416
US CL : 320/134, 136; 324/433, 434; 180/65.3
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 320/134, 136; 324/433, 434; 180/65.3

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS, JAPIO, DERWENT

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y<br>---<br>A | US 6,081,098 A (BERTNESS et al.) 27 June 2000 (27.06.00), see entire document. | 1-4<br>-----<br>5-15 |
| Y<br>---<br>A | US 6,072,300 A (TSUJI) 06 June 2000 (06.06.00), see the abstract. | 1-4<br>-----<br>5-15 |
| X | US 5,717,937 A (FRITZ) 10 February 1998, (10.02.98) see fig. 1. | 16 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| | |
|---|---|
| Date of the actual completion of the international search<br>17 July 2000 (17.07.2000) | Date of mailing of the international search report<br>31 JUL 2000 |
| Name and mailing address of the ISA/US<br>Commissioner of Patents and Trademarks<br>Box PCT<br>Washington, D.C. 20231<br>Facsimile No. (703)305-3230 | Authorized officer<br>Peter S. Wong<br>Telephone No. 703-308-[illegible]782 |